Multibeam Mapping of the Uncertainty of the Seafloor in the Southern East China Sea

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LONG-TERM GOALS

The long-term goal of the Quantifying, Predicting and Exploiting Uncertainty DRI is to understand and exploit (if possible) the fundamental acoustic, oceanographic, bathymetric and geoacoustic uncertainties of the tactical naval environment, and demonstrate how they may be exploited tactically or strategically in an Exercise Area. Focussing on the seabed, our goals are to understand the fundamental tactical and strategic uncertainty of the bathymetric and geoacoustic environment, and develop methods for their representation, visualization, computation and manipulation in a manner consistent with models of sonar performance estimation and prediction.

OBJECTIVES

The scientific objectives of the UNH team are:

1. Understand the sources and magnitudes of bathymetric and geoacoustic uncertainty in the Southern East China Sea Exercise Area, and their implications for acoustic modelling in the field experiment.
2. Develop a framework methodology for expression of user-relevant uncertainty in the bathymetric and geoacoustic context.
3. Develop appropriate representation/visualization techniques for the uncertainty models developed.
4. Provide continually updated “best available” estimates of bathymetry, backscatter and uncertainty models to the QPE technical group.

APPROACH

Due to requirements for data control via a Limited Distribution statement, the work covered here was administratively split between grant N00014-08-1-0786 and contract N00014-08-M-0244. We describe here, for convenience, the approach and other details for both instruments.

Bathymetry and geoacoustic uncertainty are primary drivers in the acoustic propagation problem, defining one of the complex boundary conditions for the ocean waveguide. The roles of the two

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14. ABSTRACT
The long-term goal of the Quantifying, Predicting and Exploiting Uncertainty DRI is to understand and exploit (if possible) the fundamental acoustic, oceanographic, bathymetric and geoacoustic uncertainties of the tactical naval environment, and demonstrate how they may be exploited tactically or strategically in an Exercise Area. Focussing on the seabed, our goals are to understand the fundamental tactical and strategic uncertainty of the bathymetric and geoacoustic environment, and develop methods for their representation, visualization, computation and manipulation in a manner consistent with models of sonar performance estimation and prediction.

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components can often be complementary, however, with bathymetry being very significant in areas of complex and steep relief, and geoacoustic uncertainty being significant in otherwise undistinguished bathymetric environments (Holland, 2006). Both, however, are typically poorly sampled spatially and temporally in most tactical environments, although they can be well characterized when sampling is done. Understanding the variability of the unobserved, therefore, is critical to characterizing and exploiting the uncertainties that are significant for the tactical environment.

We have previously developed and adapted algorithms for characterization of high-density bathymetric data [Hare *et al*., 1995; Calder & Mayer, 2003], and proposed methods for characterization of low-density data [Calder, 2006; Goff *et al*., 2006], and our approach to the fundamental uncertainty of the bathymetric data will follow these methods. In particular, starting with a high-resolution bathymetric dataset in a target area, sub-sampled to resemble the data density more typically achieved with tactical surveys and then reprocessed to give estimates everywhere, we hypothesize that the *ab initio* estimated uncertainty of the data can be calibrated, allowing an important check on our current production models in the Southern East China Sea Exercise Area. This will, moreover, allow us to determine the likely observability of small bathymetric features (e.g., sand ridges [Liu *et al*., 2000]) that might be present and significant.

The uncertainty of unobserved geoacoustic features, e.g., mud volcanoes or pock-marks [Yin *et al*., 2003] (which are often associated with the presence of gas in the sediment, and the effusion of gas into the watercolumn), is much less well defined. Information on the likely occurrence in the area and the effects of such features on the acoustic propagation path are sparse, although we will utilize backscatter data from all available high-density multibeam surveys to attempt some assessment of this. We hypothesize, however, that while deterministic information on the locations of geoacoustically active features is unlikely to ever be available, a stochastic description of their mean effect might be effective in an uncertainty-augmented acoustic propagation scheme. We are therefore developing suitable spatial statistical models, based on the inferred acoustic groundtruth from backscatter and other pilot-program observations, to allow for such incorporation, and the visualization and representation techniques to allow them to be fully exploited.

The sources for all of our research under this program are high-density bathymetric, acoustic backscatter and watercolumn observations; these data are also essential for planning and development of the field experiment. The opportunity for new data collection being limited, we have assembled the dataset from public and government databases, and continue to add new data as observations are made during the pilot and field experiments. Coarse bathymetric products suitable for public release can then be made as required and published on the QPE website, and specialized products are made on request; we continue to maintain a geospatial database for the data, including visualization products. Limitations on distribution of data from some sources mandate that high-resolution bathymetric and backscatter products cannot be publicly distributed. These data are maintained separately, and products are released only as required (to qualified recipients).

WORK COMPLETED

Database Assembly & Product Creation: We have considerably increased the contents of the raw data holdings for the Southern East China Sea Exercise Area during the reporting period, primarily with the inclusion of a publicly available low-resolution surface grid for bathymetry, and several Limited Distribution high-resolution (multibeam raw data) datasets containing both bathymetry and acoustic backscatter data. We have produced, for general use within the QPE DRI, various versions of

the low-resolution data, including derived products such as overlays interpreting the data, and profiles through the data to assist with planning for the pilot program. All public products have been made available for the QPE website. Bathymetric and backscatter products from the Limited Distribution data have also been constructed for use consistent with the "Distribution D" statement under which it was supplied. We have also solicited further data from other QPE investigators by providing locations in which new observations would be beneficial.

Spatial Models for Unobserved Variability: We have developed a preliminary model for unobserved objects using the example of bathymetric features to bootstrap the process, and the metric of grounding probability to illustrate their usage.

RESULTS

Publicly Available Data: An example of the publicly available data is shown in Figure 1, illustrating the shelf-edge near the Mien Hua Canyon complex, and the associated Exercise Area box. The data shows some complexity in the shelf edge, but suffers from artifacts in the construction of the grid provided as source, which limit the utility to planning rather than analysis. Typical products, such as the poster-sized planning chart shown in Figure 2 were also developed, including profiles derived from the same source for use in planning the pilot study.

Spatial Models for Unobserved Variability: An example of the output of the current model is shown in Figure 7. Here, marked spatial (non-homogeneous, Poisson) point process models [Cressie, 1993] are used to model the rate of unobserved bathymetric features, with the mark distributions modeling the height of the unobserved features. A simple metric of probability of grounding is used to illustrate a spatially averaged summary based on stochastic descriptions of the plausible effects of these models rather than deterministic knowledge of all of the data. The effects of the mark distributions on the observed clearance are modeled (Figure 8), showing that the marks are only significant where other data is lacking (e.g., in the deeper water); effects such as update of the local posterior distribution due to time-sequences of observation and local-to-global mappings of probability are also included in the model. A similar process applied to geoacoustic data rather than bathymetric data would be used to interpret their effects on acoustic propagation uncertainty.

IMPACT/APPLICATIONS

The availability of high-resolution bathymetric and acoustic backscatter data allows for the development of better bathymetric uncertainty estimates and acoustic backscatter mosaics to inform the planning and operational aspects of the current DRI as well as in the general tactical environment. These also allow for calibration of sparse uncertainty models in bathymetry, and for the potential identification of geoacoustically active features in backscatter, leading to improved modeling of such effects. Development of flexible stochastic descriptions of bathymetric and geoacoustic phenomena that are frequently unobservable with available tactical measurement technologies provides for methods that may account for their effect within acoustic propagation models which are uncertainty-augmented.

RELATED PROJECTS

None

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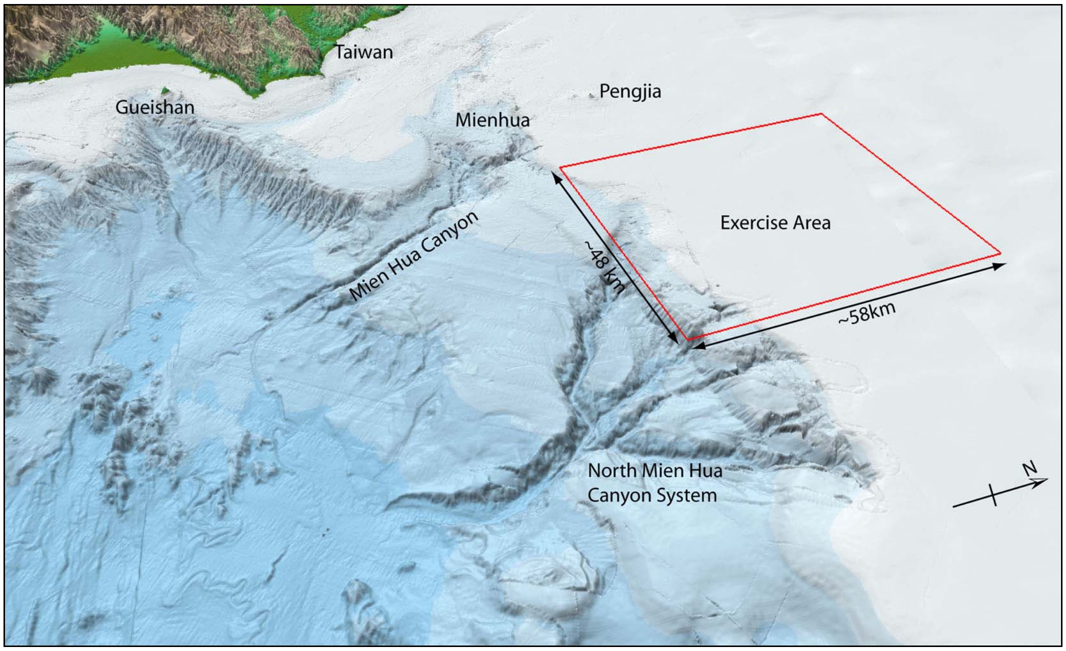

Figure 1: Perspective overview of the publicly available bathymetry with Exercise Area box (vertical exaggeration ×6). The gridded source data has a number of artifacts that make it suitable only for planning, but still shows sufficient detail in the target area to be useful.

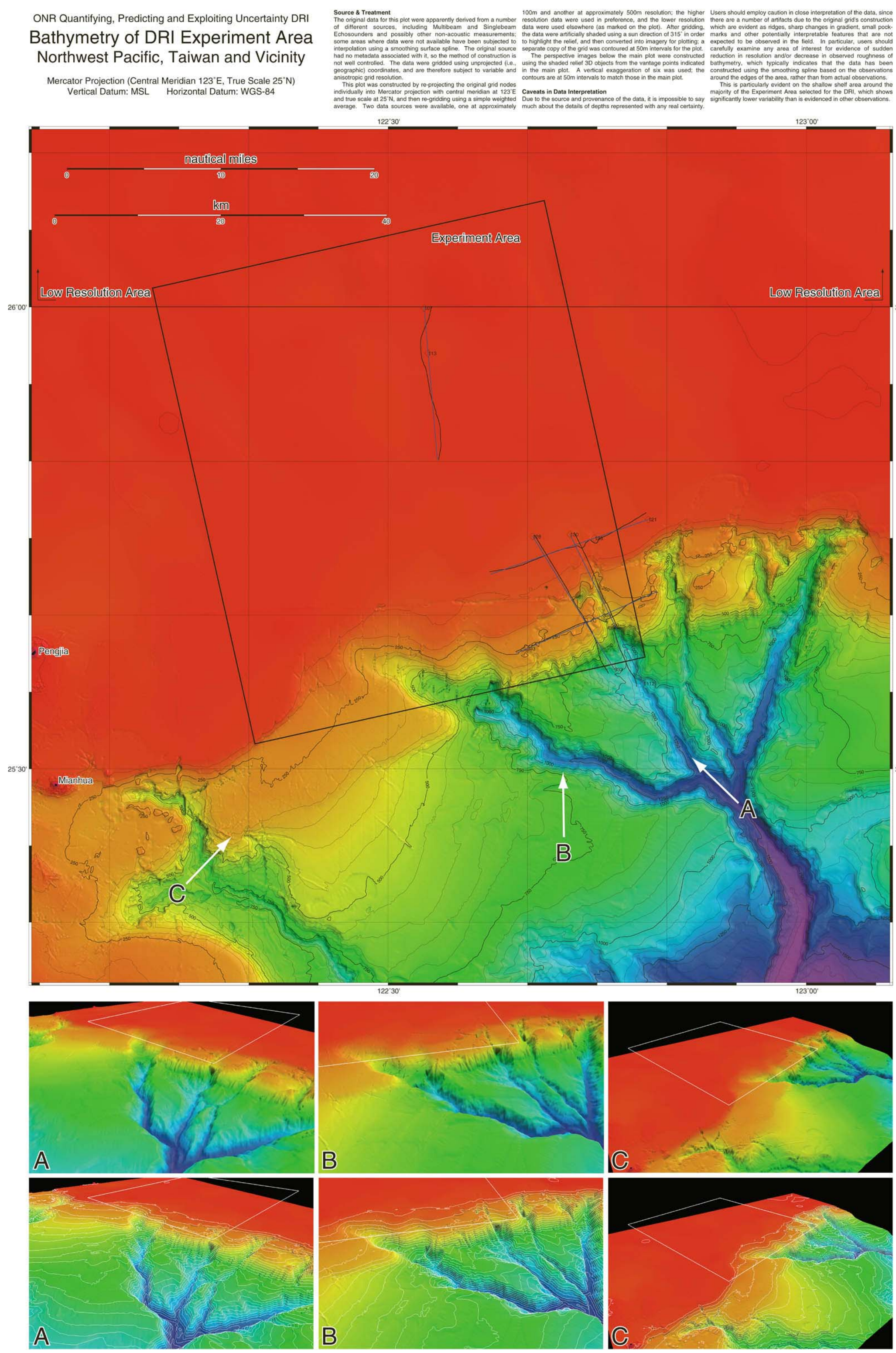

Figure 2: Example of poster-sized products from publicly available data used for planning, including profiles from the bathymetry in areas of interest and perspective views of the bathymetry to illustrate slopes and canyon complexities. Original size of image is 0.64×0.95m.

Figure 3-6: These figures describe results derived from the Limited Distribution data, and cannot be reproduced in this document; full details are available in the "Distribution D" version of this report.

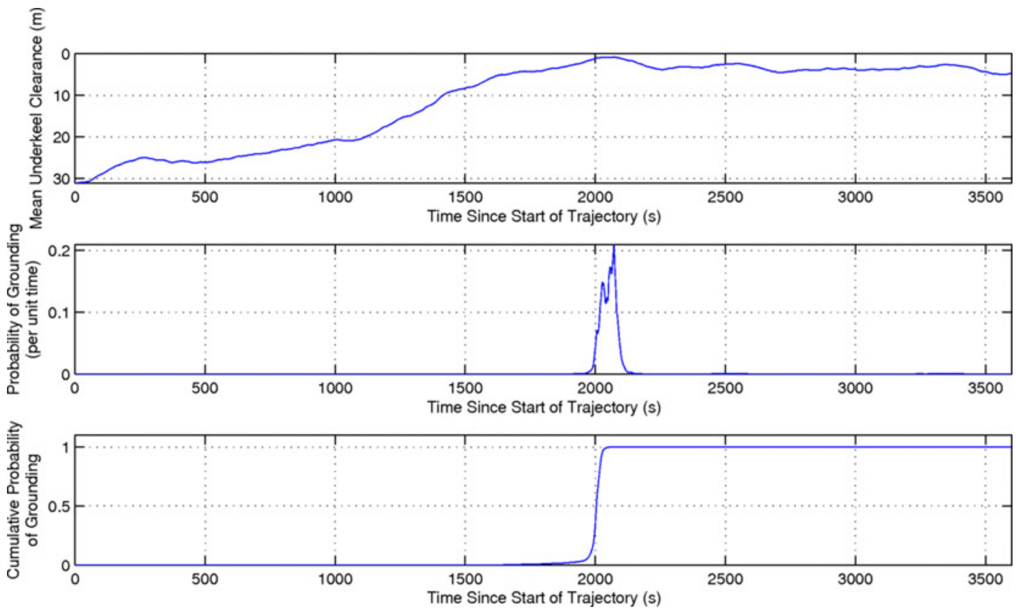

Figure 7: An example of the marked spatial (non-homogeneous, Poisson) point process models in use to describe the mean stochastic effect of unobserved bathymetric features, using probability of grounding as an output metric. Here, the effect of the unobserved object's height on the clearance for a surface vessel result in modulation of the probability of grounding that depends on local spatio-temporal history, global circumstances, and the stochastic characterization of the unobserved.

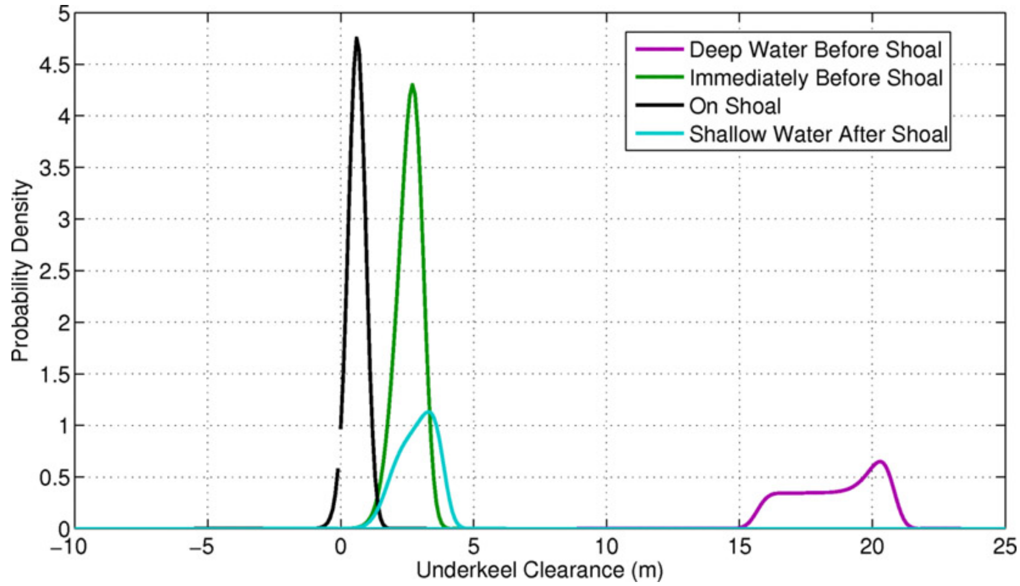

Figure 8: Examples of typical probability distributions driving the simulation of Figure 7. The effects of the unobserved object distributions are evident in the non-Gaussian shape of the clearance distribution in deep water [purple curve] (one of the unobserved is modeled as uniform in height over a ~5m range), but such differences are not as significant in shallow water [black, green curves]; some recovery of effect is evident after the primary shoal [cyan curve] as circumstances stabilize.